REPLY TO REVIEWERS

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Title: Correlation between seismic activity and acoustic emission on the basis of in-situ monitoring

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The authors thank the Editor and the Reviewers for their useful remarks. The recommendations helped the authors in preparing an improved version of the manuscript.

Concerning the list of comments, a detailed answer is provided below. All the changes required are highlighted with a yellow background in the revised manuscript.

REVIEWER 1

In this study, an in-situ experimental campaign was conducted on a granite underground tunnel located in Southeast China. The objective was to analyze precursor parameters employed on AE time series and its relationship with seismic events recorded. The AE and its temporal correlation to the incoming seismic events were analyzed by considering the multi-modal statistical analysis, b-value, and the natural-time variance. The research topic is important from the point of view of phase transition phenomena and mining engineering. However, some points should be improved.

It is recommended that the present manuscript be accepted following the implementation of significant revisions. Some general observations to improve the manuscript clarity and quality are listed:

(1) Figure 2 is similar to the one presented in [x1], therefore, it is recommended to clarify that this figure is modified or redrawn to avoid copyright issues.

[x1] https://doi.org/10.1016/j.engfracmech.2016.01.013

Following the Reviewer's suggestion, the manuscript has been revised as follows:

<< …

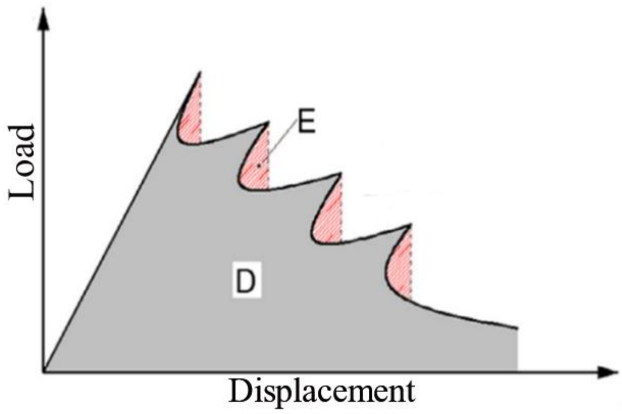

Figure 2: Multiple snap-back instabilities (Modified from Carpinteri et al. 2016).

…>>

(2) Some sentences can be added about the recent application of natural time on AE time series in order to identify the imminent failure of materials and structures. The review and comments should cover more new studies, such as those presented in [x2-x5], but not limited to these.

[x2] https://doi.org/10.1016/j.physa.2019.123831

[x3] https://doi.org/10.3390/app12083918

[x4] https://doi.org/10.3390/app12041980

[x5] https://doi.org/10.3390/app13106261

Following the Reviewer's suggestion, the manuscript has been revised as follows:

<<…Recently, natural time analysis has been applied to identify the imminent failure of materials and structures (Loukidis et al., 2020; Ferreira et al., 2022a and 2022b; Triantis et al., 2023)…>>

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[32]Loukidis, A., Pasiou, E. D., Sarlis, N. V., and Triantis, D. Fracture analysis of typical construction materials in natural time, Physica A, 547, 123831. https://doi.org/ 10.1016/j.physa.2019.123831, 2020.

[33]Ferreira, L. F., Rojo, N. B. T., Bordin, A. C., Sobczyk, M., Lacidogna, G., Niccolini, G., and Iturrioz, I. Analysis of acoustic emission activity during progressive failure in heterogeneous materials:

experimental and numerical investigation, Appl Sci-Basel, 12, 3918-3918. https://doi.org/10.1016/j.physa.2019.123831, 2022a.
[34]Ferreira, L. F., Silva, É. C., Bordin, A. C., Rojo, N. B. T., Sobczyk, M., Lacidogna, G., and Ignacio, I. Long-range correlations and natural time series analyses from acoustic emission signals, Appl Sci-Basel, 12, 1980. https://doi.org/10.3390/app12041980, 2022b.
[35]Triantis, D., Stavrakas, I., Loukidis, A., Pasiou, E. D., and Kourkoulis, S. K. A study on the fracture of cementitious materials in terms of the rate of acoustic emissions in the natural time domain, Appl Sci-Basel, 13, https://doi.org/10.3390/app13106261, 2023. >>

(3) In order to clarify the article, please provide more details on how "the impact of environmental ultrasonic noise, such as that from traffic, human activities and wind" has been eliminated.

The site of the experiment is an all-granite dedicated underground tunnel, which is far away from the noise sources of traffic, human activities, wind noise, etc. This dedicated tunnel is a seismic observation platform located in southeastern China, deep into the mountain up to 150 m. In addition, the soil and tunnel structure provide sound-absorbing and sound-insulating effects, reducing external noise transmission. By considering the Reviewer's suggestion, the manuscript has been revised as follows:

<<…This all-granite tunnel is excavated horizontally into the mountain up to 150 m, and is mainly used to install seismic observation instruments, detecting seismic data such as crustal deformation and underground fluids. All the seismic station equipment is connected to the National Seismic Monitoring Network. This dedicated tunnel is far away from the noise sources of traffic, human activities, and wind noise, minimising the interference of external environmental factors. In addition, the soil and tunnel structure provide sound-absorbing and sound-insulating effects, reducing external noise transmission. >>

(4) Please provide the criteria used to identify the optimal Gaussian fit in the multimodal analysis and the parameters of the Gaussian fit used to plot Figure 12. This information is relevant for other researchers wishing to apply a similar approach.

Following the Reviewer's suggestion, the manuscript has been revised as follows:

<< A multi-modal (Gaussian and multi-peak) statistical analysis is carried out by means of Microcal Origin, identifying the relative maxima of AE and seismic distributions by best Gaussian fitting. The optimal Gaussian fitting reproduces all the peaks, minimising the gap between the predicted values and the actual data. In particular, starting from the discrete distribution of data and following an iterative procedure, in which the curve offset, y_0, centre coordinate, x_c, width, w, and amplitude, A, are considered, the multi-modal curve that best approximates the discrete distribution of points is identified by the following equations (Fig.10). >>

<< The superposition of AE and earthquake distributions is shown in Fig.10(c), where it is evident the strong correlation between seismic swarms occurring in the monitored area and AE signals, as well as the precursor role played by AE with respect to imminent earthquakes. The Gaussian fitting parameters employed to plot Fig.10(c) are the following: Centre coordinate (x_c): 148, 165, 556, 573; Curve offset (y_0): 22, 1.1, 22, 1.1; Amplitude (A): 339.0, 2.0, 261.3, 1.3; Width (w): 32.8, 24.0, 32.8, 19.0. >>

(5) Please clarify the methodology employed to calculate the b-value. Was a moving event window employed, or was a time window considered?

The manuscript has been revised as follows:

<<…The *b*-value is the negative slope of the GR law straight line, which is fitted by the least squares method. In this study, the temporal variation of the *b*-value is estimated by the moving event window method. A number of events, N, equal to 400, and a time window step of 200 events are adopted for the evaluation of the *b*-value temporal variation. …>>

(6) It is known that several parameters can be applied to the energy term (P_K) in the analysis of natural time, such as amplitude, rise angle and AE energy (see, for example, Refs [x2-x5]). Which parameter was used by the authors? Please clarify.

In our study, we calculated the AE energy for each event and used it as the P_K value for analysing the natural time, thus revealing the trend and the characteristics of the system in critical state. Natural-time series transform time series into the natural-time domain neglecting the time intervals of consecutive events, only considering the order and energy of occurrence. Among N events, the energy of events is defined as Q_k, χ is defined as normalized index of energy Q_k, $\chi_K = K/N$ Normalized energy $P_K = Q_K / \sum_{i=1}^{N} Q_i$ is a probability distribution of discrete variable χ_K. The text of the manuscript has been revised as follows:

<<…Based on the time-series analysis of N events read in a new time domain, namely the natural time, χ, a method to identify critical states was developed (Varotsos et al., 2011 and 2013). The variance κ_1 of the natural time is defined as:

$$\kappa_1 = \sum_{k=1}^{N} p_k \chi_k{}^2 - \left(\sum_{k=1}^{N} p_k \chi_k \right)^2 = \langle \chi^2 \rangle - \langle \chi \rangle^2 , \quad (4)$$

where $\chi_K = K/N$ is the normalized index of energy Q_k (related AE energy), and $P_K = Q_K / \sum_{i=1}^{N} Q_i$ is the probability distribution of the discrete variable χ_K. When κ_1 converges to 0.07, the critical state is imminent. >>

(7) Why is there no critical time for EQ.2 in the natural time analysis? Even if the natural time parameters do not converge to EQ.2, a future study can be proposed for this.

The main focus of the present study is on the multi-modal statistical analysis, which proves to be an effective tool for earthquake prediction. In addition, by means of the natural time analysis, we identify the critical time for EQ.1 event. Although we did not find the critical time of the EQ.2 event with natural time analysis, future works could improve the natural time algorithms to accommodate a wider range of seismic intensities and to increase the accuracy of the critical time prediction. Meanwhile, we need to further collect and analyse more experimental data from stronger earthquakes to determine the effectiveness of the natural time method, which, in this work, could be considered merely as a confirmation of the multi-modal statistical analysis.